WHITE PAPER

USDA Forest Service Pacific Northwest Region Umatilla National Forest

WHITE PAPER F14-SO-WP-SILV-5

Site Productivity Estimates for Upland Forest Plant Associations of the Blue and Ochoco Mountains[1]

David C. Powell; Forest Silviculturist
Supervisor's Office; Pendleton, OR

Initial Version: **SEPTEMBER 2010**
Most Recent Revision: **DECEMBER 2014**

INTRODUCTION

Site productivity is an important characteristic of forest ecosystems. Not only does productivity affect how much timber volume an area can produce, but it can be thought of as an "ecological engine" powering vegetation change – it controls the speed at which shade-tolerant species get established beneath shade-intolerant trees, the rate at which forests produce and accumulate biomass, and the response of composition and structure to fire, insects, pathogens, and other disturbances.

This white paper provides site productivity estimates for seven tree species (ponderosa pine, interior Douglas-fir, western larch, lodgepole pine, grand fir, Engelmann spruce, and subalpine fir) and for 42 upland-forest plant associations described for the Blue and Ochoco Mountains of northeastern Oregon and southeastern Washington (Johnson and Clausnitzer 1992). The plant associations are organized further into potential vegetation groups (Powell et al. 2007). Since site quality, site productivity, site index, and other terms are often used interchangeably (and sometimes incorrectly so), this paper begins with a summary of important terminology.

Terminology Notes (based on Helms 1998)

Site productivity is assumed to be a synonym for site quality. Site quality is defined as "the productive capacity of a site, usually expressed as volume production of a given species." Note that a site quality or site productivity class is usually determined by using site index. Productivity is defined in an ecological context as "the rate at which biomass is produced per unit area by any class of organisms." Note that productivity refers to a ***rate*** of biomass production, so it reflects a site's intrinsic capability to grow trees. Production, however, refers to the amount of goods or services produced by an area – there is no connotation of the rate at which a good or service is produced (if a site has

[1] White papers are internal reports and have received only limited review. Viewpoints expressed in this paper are those of the author – they do not necessarily represent positions of the USDA Forest Service.

10,000 board feet per acre, was it produced in 50 years or 250 years?). This means that productivity and production are not synonymous terms. Site is defined as “the area in which a plant or stand grows, considered in terms of its environment, particularly as this determines the type and quality of the vegetation the area can carry.”

CONCEPTS AND PRINCIPLES

The potential species composition, forest structure, and stand density of forest sites vary in response to changes in landform, topography, climate, soils, slope exposure, geology, and other physical site factors (Powell et al. 2007). Changes in these abiotic factors are the source of variation in site productivity. Since productivity is related to intrinsic factors such as landform and soil depth, these site-level characteristics are commonly referred to as ‘ecological site potential’ because they are perceived to be as permanent as the land itself (Daubenmire 1973).

A common system for estimating ecological site potential involves the use of plant associations. This classification unit of ‘potential vegetation’ has much in common with site productivity because the land area supporting a plant association is considered to integrate variation in elevation, soil, geology, and related factors in such a way that it will support the same climax overstory and understory vegetation (Davis et al. 2001). Because site productivity and potential vegetation are both controlled by abiotic factors (geology, soils, etc.), it is sometimes confusing as to how they differ.

Two primary factors affecting forest site productivity are soil characteristics (nutrient status, rooting depth, drainage, texture, etc.) and moisture availability within the tree rooting zone. It would certainly be possible, although difficult and time consuming, to estimate site productivity by measuring important soil and moisture characteristics directly. Generally, the direct measurement approach is only practical for research purposes.

Because of the strong linkage between soils and site productivity, many studies have attempted to correlate soil mapping units with site quality (Base and Fosberg 1971, Brown and Loewenstein 1978, Carlson and Nimlos 1966, Chen et al. 2002, Monserud et al. 1990, Sprackling 1973, and others). Unfortunately, correlation between soil mapping units and site index has often been poor.

For forest ecosystems, poor correlation between site productivity (e.g., site index) and soil types is thought to reflect the fact that soils are often not classified and interpreted by using factors with a direct influence on tree growth, such as drainage class, thickness of the surface horizon, and subsurface horizon depth (Davis et al. 2001). In northern Idaho, for example, it was found that the height of ponderosa pine trees for a given age corresponded to soil depth down to bedrock, or down to a closely packed, mottled soil (Parker 1952). But studies for other tree species, or for other geographical locations, have not necessarily identified total soil depth as an important factor affecting productivity.

BACKGROUND: SITE INDEX AND YIELD CAPABILITY

Site index (SI) is defined as “a species-specific measure of actual or potential site quality, expressed in terms of the average height of trees included in a specified stand component” such as dominant and codominant trees (Helms 1998). SI is derived by measuring total height and age (either breast-height age, or total age) for ‘top-height’ trees defined as the dominant and codominant crown classes in a stand, and then using the height and age measurements to calculate an SI value.

By definition, SI provides the potential height of dominant and codominant trees, which are the tallest trees in an even-aged stand or the topmost layer in a multi-layered stand structure. This means that SI does not provide an estimate of average stand height because certain crown classes (intermediate and subordinate trees) are intentionally not sampled when selecting site trees.

If the site trees selected for measurement are chosen carefully, and if they meet the specifications of the published SI curves (such as lack of top damage from budworm or defoliating insects, little or no evidence of growth suppression in the increment core, etc.), then the SI values are assumed to provide an accurate assessment of inherent site quality.

SI values are expressed in feet – an SI value of 70 means that the total height for dominant and codominant trees at 50 years of age (if the site index curves use 50 years as a reference age) would average 70 feet. If the curves use 100 years as a reference age, then an SI value of 70 means that dominant and codominant trees would average 70 feet in total height at 100 years of age.

Site index values pertain to a reference age (such as 50 years or 100 years), and reference age varies from one set of published curves to another. Reference age functions as an 'indexing' mechanism because it scales all measurements to a common baseline, without which it would be difficult to know if top-height differences reflect site quality variation, or the fact that a sampled stand had more time to grow (it was older) than another sampled stand. Published sources of SI curves for the Blue Mountains are provided in table 1.

Table 1: Source of site index curves for major tree species of the Blue Mountains.

Tree Species	Species Code	Site Index Source	Reference Age (Years)	Age Limit (Years)
Engelmann spruce	PIEN	Brickell 1970	50 (total)	≤ 200
Grand fir	ABGR	Cochran 1979b	50 (BH)	≤ 100
Interior Douglas-fir	PSME	Cochran 1979a	50 (BH)	≤ 100
Lodgepole pine	PICO	Dahms 1975	90 (BH)	≤ 120
Mountain hemlock	TSME	Means et al. 1986	100 (BH)	≤ 240
Ponderosa pine	PIPO	Barrett 1978	100 (BH)	≤ 140
Subalpine fir	ABLA2	Brickell 1970	50 (total)	≤ 200
Western larch	LAOC	Cochran 1985	50 (BH)	≤ 100
Western white pine	PIMO	Brickell 1970	50 (total)	≤ 105
Whitebark pine	PIAL	Hegyi et al. 1981	100 (total)	≤ 300

Sources/Notes: Species code is an alphanumeric code used for species identification in the CVS database; "BH" in the reference age column indicates that the reference age pertains to a breast-height age rather than a total age; the age limit is the age range of measured site trees for which the site index curve is applicable.

CVS PLOTS AS A DATA SOURCE

In the 1990s, the Blue Mountain national forests installed a grid-based inventory system called the Current Vegetation Survey (CVS) (USDA Forest Service 1995). CVS plots were installed on a 1.7-mile grid (each plot was located 1.7 miles away from adjoining plots) except for designated Wilderness areas, where the grid spacing was 3.4 miles between plots.

For the Blue Mountains national forests of northeastern Oregon, southeastern Washington, and west-central Idaho, the initial installation of forested CVS plots occurred in 1993 and 1994; nonforest CVS plots were established across all three national forests in 1995 and 1996. Plot information collected during this 1993-1996 period is referred to as occasion 1 data. Since their initial installation, every CVS plot has been remeasured once and this subsequent information is referred to as occasion 2 data (Christensen et al. 2007).

When evaluating data sources providing measured values for a wide range of tree attributes, the CVS information is generally acknowledged to be the best dataset available for the Blue Mountains because its grid-based approach prevents plot location bias and its quality control/quality assurance emphasis was very high (Max et al. 1996). For this reason, it was decided to use the CVS information when calculating site index and yield capability values for the Blue Mountains.

ANALYSIS METHODOLOGY

I pooled the occasion 1 CVS data for all three of the Blue Mountains national forests (e.g., Malheur, Umatilla, and Wallowa-Whitman), and the resulting database was queried to extract the site tree records and their associated information, including the CVS plot and point numbers they occurred on. Site trees are easily identified in the database because they have a unique vegetation (tree history) code: 13.

Potential vegetation is represented in the CVS database by using ecoclass codes (Hall 1998). Each CVS plot consists of a 5-point cluster, and an ecoclass code was recorded for each of the five points. Site trees are coded to the point they occur on or near, so an ecoclass code was readily assigned to each site tree record by using a database query and the CVS plot and point identifiers as common fields linking the ecoclass and site index tables.

After 6,664 site tree records were extracted from the CVS occasion 1 database (i.e., all records with a vegetation code of 13 were extracted), the data was filtered to remove problem records. Problem records generally had one of two issues:

(1) they are missing a measured height or age value, which means that a site index value could not be calculated for them, or

(2) the recorded age value exceeds the site-index curve's age limit, which varies by tree species (the final column in table 4 provides age limits for each site-index curve).

Certain site index curves, particularly Cochran's curve for western larch (Cochran 1985), are very sensitive to the age limit, and age values beyond the limit quickly produce nonsensical results. A total of 155 problem records were removed from the dataset, resulting in 6,509 usable records for further analysis.

The analysis dataset was then transferred to Excel and stratified by potential vegetation type (plant association) by using the ecoclass code associated with each record. Site index and yield capability were calculated for each record by using equations referencing measured values of tree age and tree height as input variables (site index) or calculated values of site index (yield capability). The source of calculation equations varied – some came from the published site index source document (see table 4), whereas others came from USDA Forest Service (1987) or Hanson et al. (2002).

RESULTS

By using the analysis methodology described above, site indexes were calculated and the results stratified for plant associations of the Blue and Ochoco Mountains (Johnson and Clausnitzer 1992).

It is seldom possible to directly compare site indexes from one tree species to another because reference ages vary, and some site curves use breast-height age whereas others use total age. In order to compare site productivity between tree species, yield capability was calculated.

Yield capability is a potential growth rate, in cubic feet per acre per year, for fully stocked stands on an area with a given site index. Yield capability equations were the same ones used in the Forest Service's stand examination program (USDA Forest Service 1987).

Site productivity estimates, expressed as yield capability, are provided in seven charts, one for each tree species, and they are presented on pages 8-15 (notes about the charts are on page 15). At the base of each chart, standard Forest Service productivity classes (3-7) are shown for reference.

IS SITE INDEX THE BEST PREDICTOR OF SITE PRODUCTIVITY?

Daniel et al. (1979) define site quality as the 'maximum timber crop' that forestland can produce in a given time. They go on to note that "since site quality is measured by the maximum timber crop (volume) produced within a given period, it can vary with tree species and the time element chosen." This means that "a particular area could have a different site quality depending on whether it supported Douglas-fir, western hemlock, or western redcedar" (Daniel et al. 1979, p. 236). The situation where site quality differs by tree species has also been noted for broadleaved species of the eastern U.S. (Gingrich 1964).

The concepts discussed here from the Daniel et al. (1979) text raise important questions about site quality (productivity) and its evaluation. If site quality is best evaluated in a timber production context (e.g., by determining the maximum timber crop), does this suggest that stand-level measures might be more appropriate than individual-tree measures such as site index? And if stand-level measures are considered superior to individual-tree measures, particularly for sites with low stocking capacity (MacLean and Bolsinger 1973), wouldn't some measure of inherent stockability (stocking capacity) be effective as an overall productivity indicator?

[Note: The MacLean and Bolsinger research paper describes how it is possible to locate relatively high-performing individual trees on low-productivity plant associations such as ponderosa pine/bluebunch wheatgrass and ponderosa pine/Idaho fescue. Often, these high-performing trees are growing in favorable microsite environments where more soil or water collects than is typical for the site as a whole. If the high-performing trees are selected as site trees, which often occurs because stand examination crews are trained to select only the best trees as site trees, then the resulting productivity calculations will overestimate the quality of this site (the site trees likely represent the microsites well, but they do not reflect prevailing conditions for the site as a whole).]

When considering the environment boundary-line approach (Sackville Hamilton et al. 1995), is there really any qualitative difference between maximum stand density index (SDI), expressed by tree species and plant association, and traditional productivity measures such as site index? And, wouldn't we expect sites with high carrying capacity for density (high maximum SDI) to also have high timber volume productivity (which is assumed to be analogous to yield capability, e.g., potential cubic-foot volume production at culmination of mean annual increment)?

[Note: the boundary-line approach described by Sackville Hamilton et al. (1995) shows how self-thinning populations of plants, including trees, follow size-density trajectories with a slope of approximately -3/2. *For a given tree species*, their work shows that a different size-density boundary line exists for each plant association, rather than a single line pertaining to a species as a whole.]

I believe that maximum density is an effective indicator of site quality, and I also believe it offers advantages over traditional productivity indicators such as site index. Although we may not be able to identify all of the factors involved, we know that different site factors control height growth potential (e.g., site index) than stockability (e.g., maximum SDI carrying capacity). "In a conceptual sense, stockability can be regarded as the tolerance of a forest system to the presence of and/or competition from increasing numbers of trees. This tolerance may differ with environment and, in that regard, might be considered an aspect of site quality independent of that reflected in site index or potential height growth (cf Sterba 1987)" (DeBell et al. 1989).

Maximum density (SDI) reflects productivity in a carrying capacity context – sites with higher maximum SDI values are more productive than sites with lower maximum SDI values because they have more capacity to carry (produce) tree biomass. Or to express it in a different way, tree species with higher maximum SDI values (on the same plant association) are more productive than species with lower maximum values.

Why do variations in site quality, by tree species, occur? There may be several reasons, but an important one relates to light-water tradeoff theory (Smith and Huston 1989), which postulates that *plants cannot simultaneously have high tolerance for low levels of light and water*.

Tree species adapted to water-limited sites (e.g., dry forests) are governed by a specific suite of life history traits, with dominant conifers evolved to compete for water first and light second. The light-water tradeoff theory helps explain the common situation where tree species with low shade tolerance, which tend to be early-seral species with relatively high drought tolerance, are often the first trees to experience mortality in the low-light environments associated with high stand density.

The primary disturbance process affecting dry-forest sites – recurring surface fire occurring at a frequency of 5-20 years for the Blue Mountains – creates an uneven-aged stand dominated primarily by fire-resistant ponderosa pine (Powell 2014). As long as fires continue, dry-forest stands are thinned, and competition for water is maintained at relatively low levels.

Maximum density information suggests that certain life history traits supporting ponderosa pine's survival in a frequent-fire environment (e.g., high, sparse crowns; thick bark; etc.) might represent a productivity tradeoff when compared with life history traits for a more productive species that is not adapted to high frequency fire – grand fir (which has low, dense crowns; thin bark; etc.). Thus, a low severity/high frequency fire regime would favor tree species that compete for water primarily and light secondarily (ponderosa pine). Conversely, a high severity/low frequency fire regime will promote species that compete most effectively for sunlight (grand fir).

The bottom line is that site index and maximum density (SDI) are not closely related. This is demonstrated by figure 1, which shows site index and maximum SDI values for ponderosa pine on a range of plant associations occurring in the Blue Mountains. Although not presented here, similar results are obtained when site index and maximum density are compared for the other six predominant conifers found in the Blue Mountains.

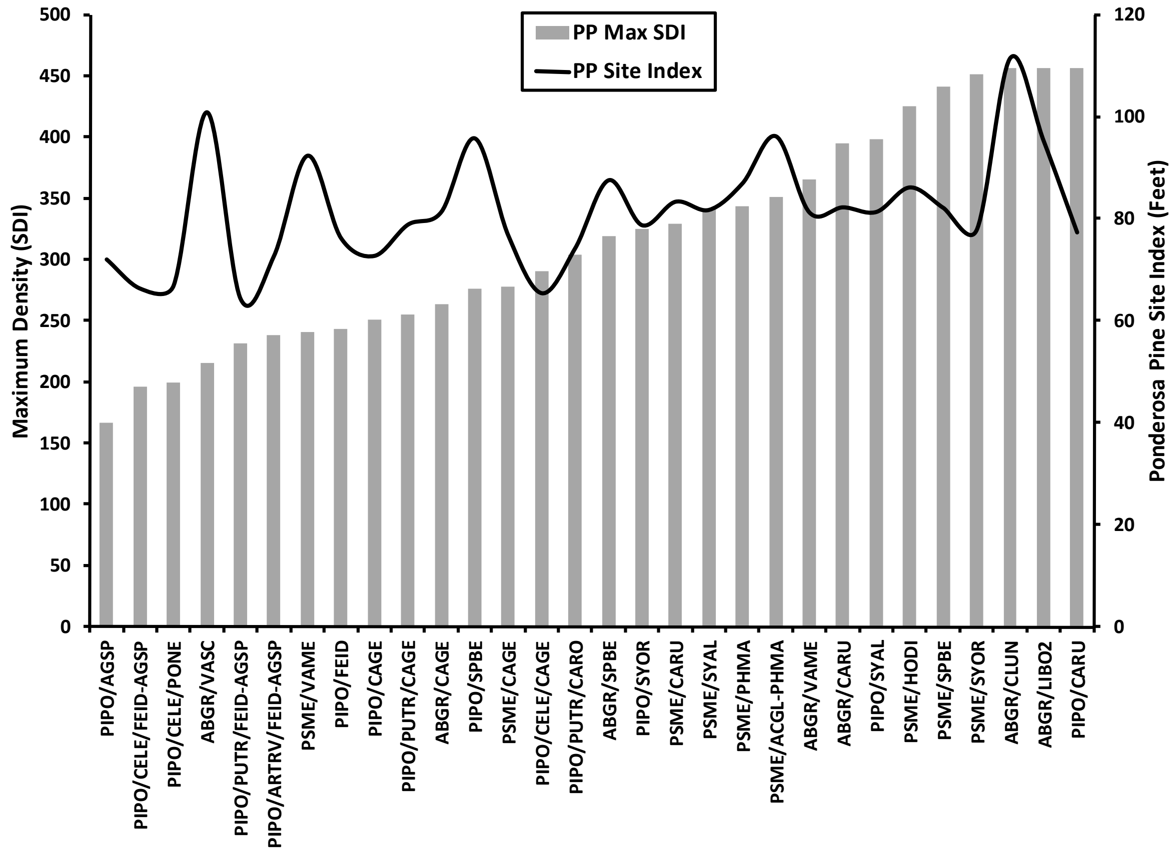


Figure 1 – Maximum density (stand density index, SDI) and site index values for ponderosa pine on a range of plant associations in the Blue Mountains of northeastern Oregon and southeastern Washington. Plant associations are ordered from those with lowest maximum density (left) to those with highest maximum density (right). Note that it is possible for plant associations with relatively low stockability for ponderosa pine (such as ABGR/VASC and PSME/VAME) to have relatively high site index values. For this reason, it can be challenging to obtain meaningful productivity estimates for tree species growing on sites where they have low inherent stockability (low stocking capacity), as described in a research paper by MacLean and Bolsinger (1973).

YIELD CAPABILITY CHARTS

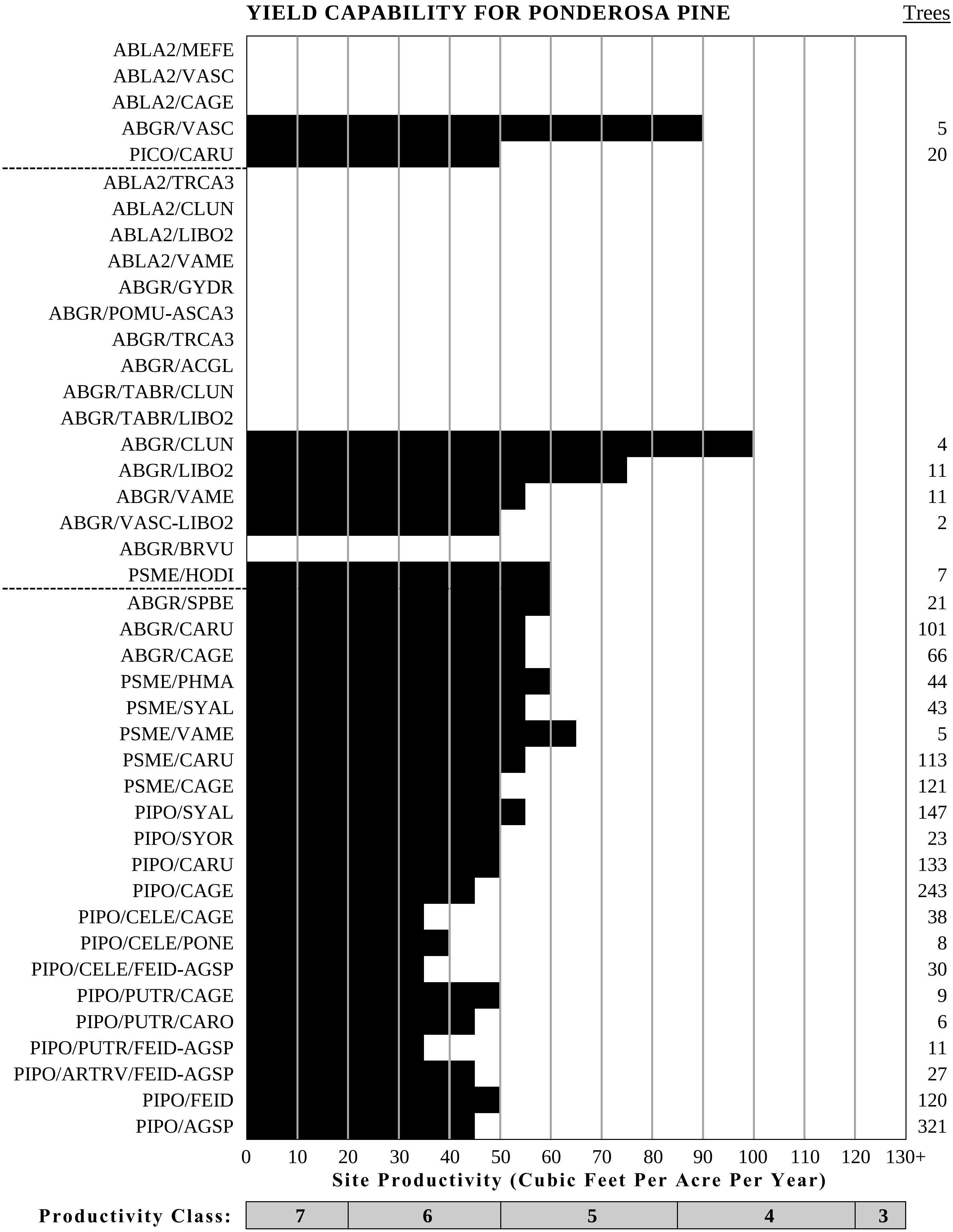
The next seven pages (pages 8-14) present yield capability charts produced during the site productivity analyses described in this white paper. Note that yield capability is defined as the potential growth rate, in cubic feet per acre per year, for fully stocked stands on an area with a given site index.

Yield capability is assumed to reflect potential stand growth rates, expressed as cubic foot volume production, at the point where a stand's growth is at culmination of mean annual increment (i.e., the point where graphical lines depicting trends in periodic annual increment and mean annual increment intersect).

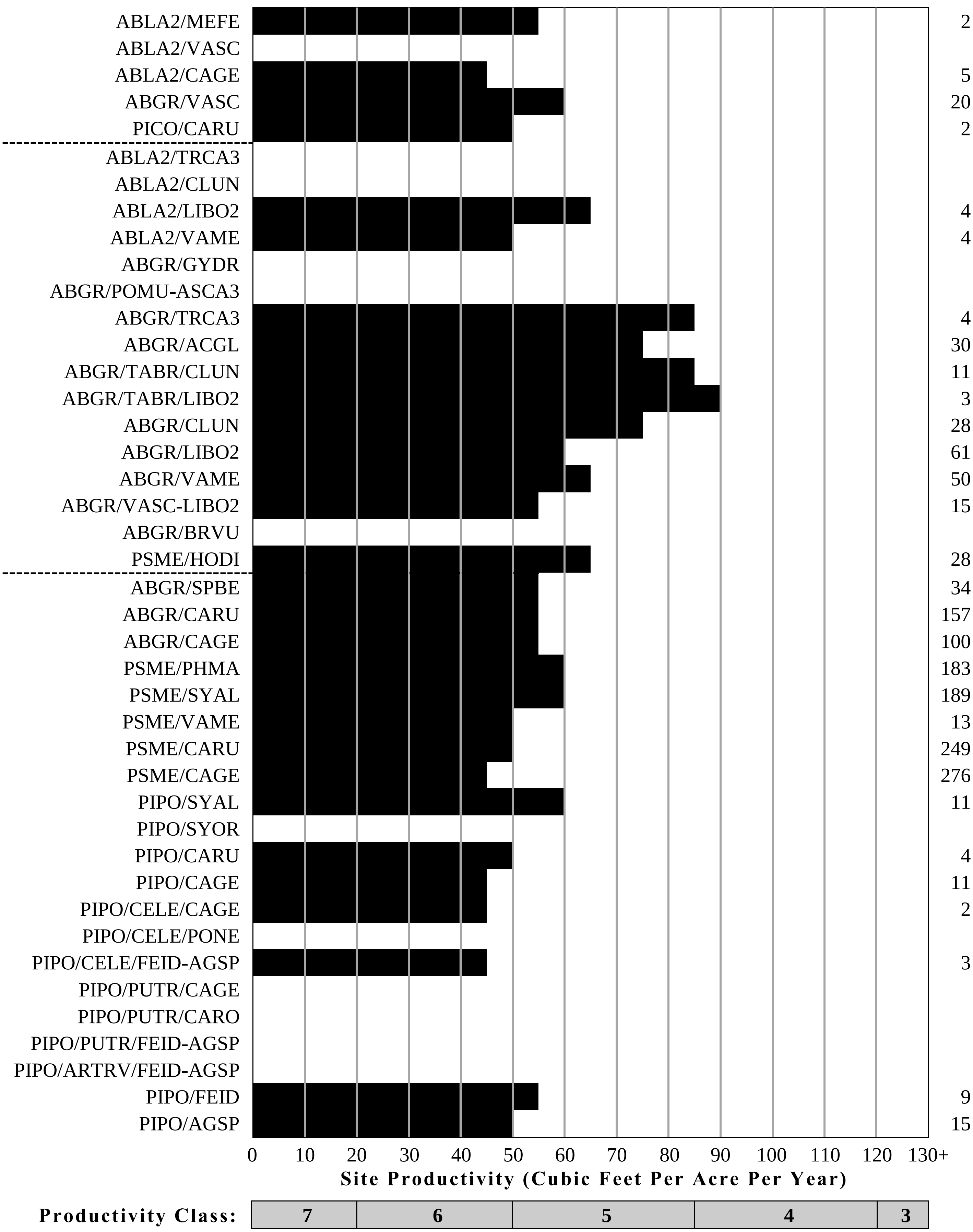
Yield capability is often calculated from site index measurements because it is not possible to directly compare site index values, between tree species, due to differences in site index curves between species.

Page 15 provides notes about much of the information presented in the yield capability charts.

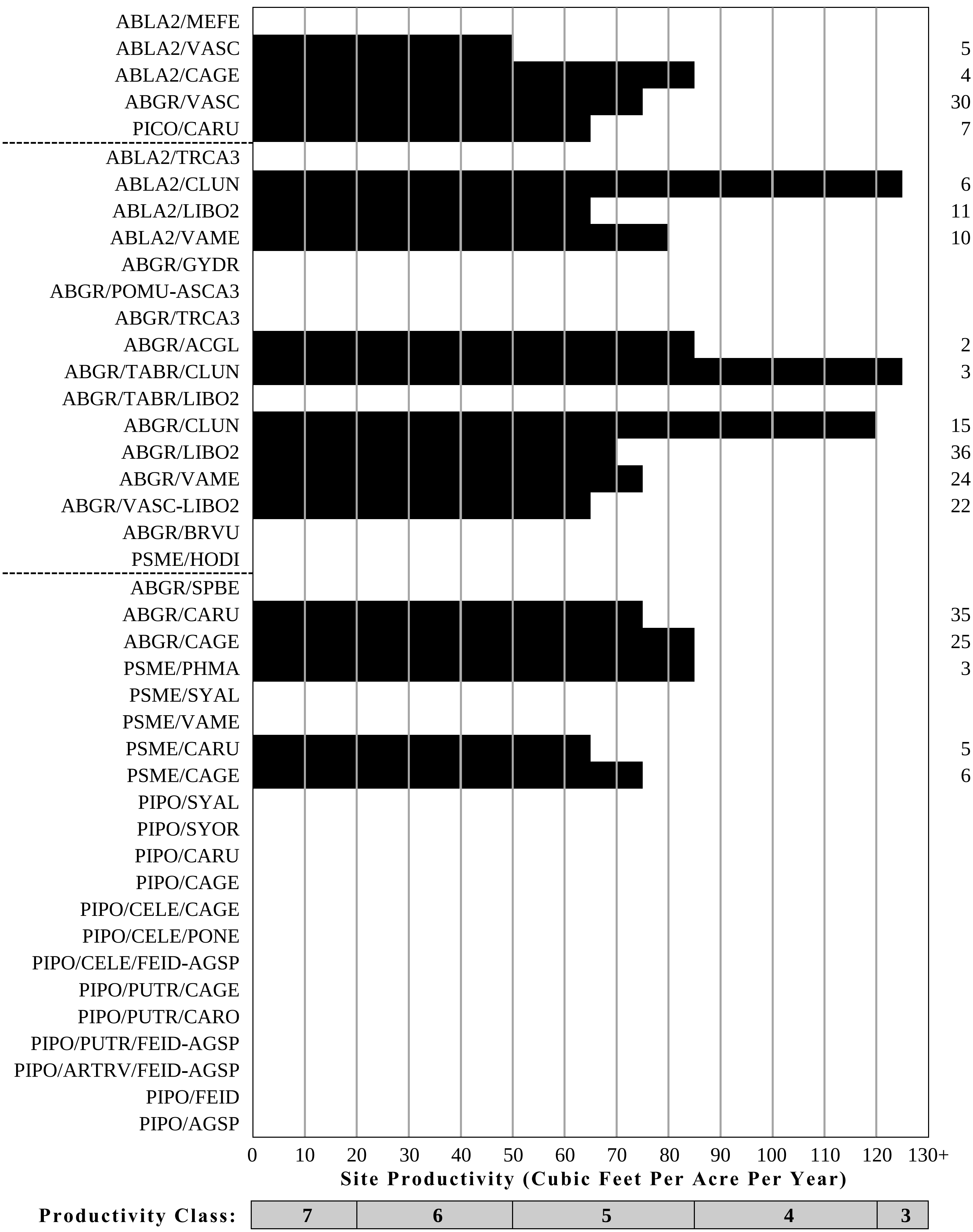
YIELD CAPABILITY FOR PONDEROSA PINE



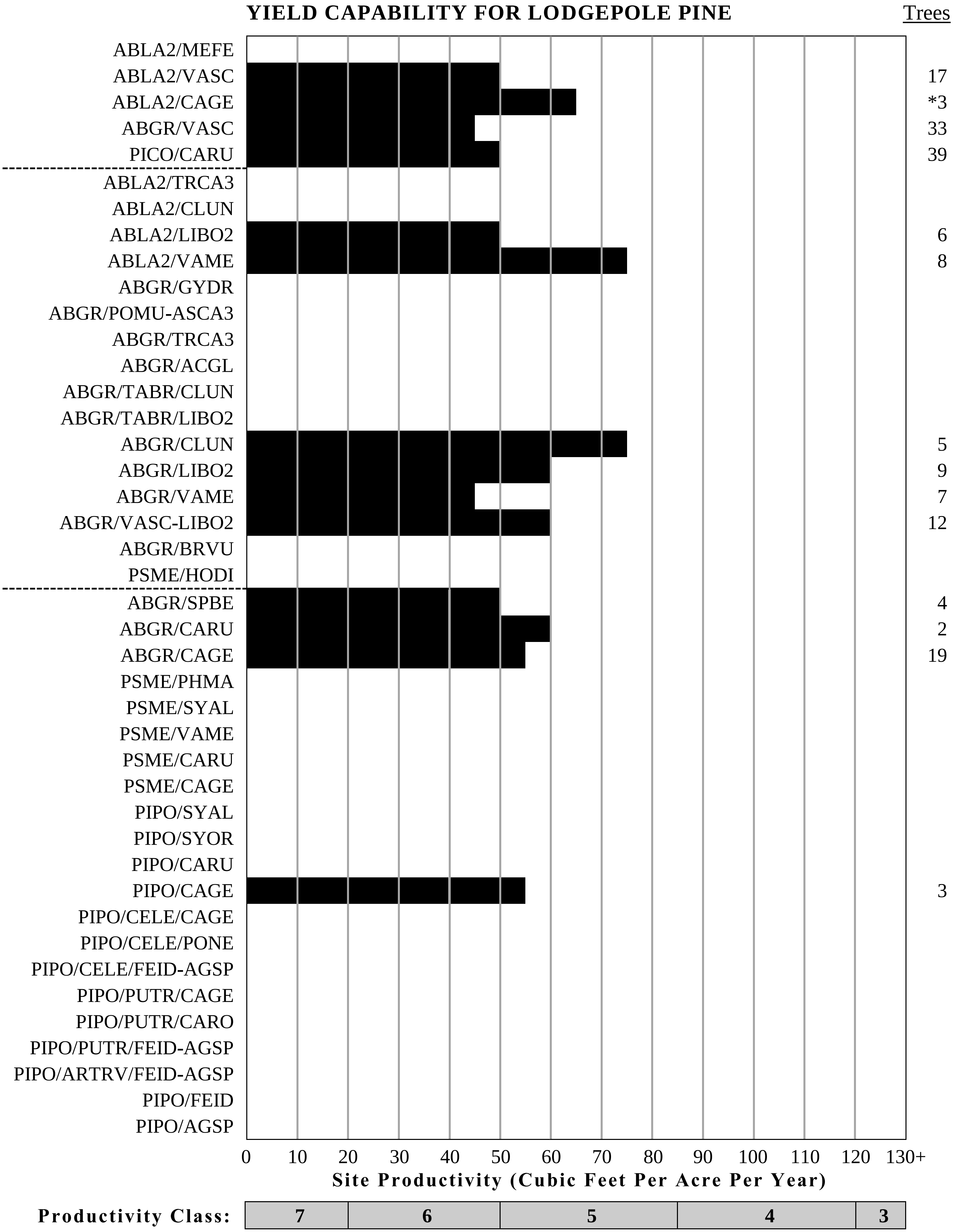
YIELD CAPABILITY FOR DOUGLAS-FIR



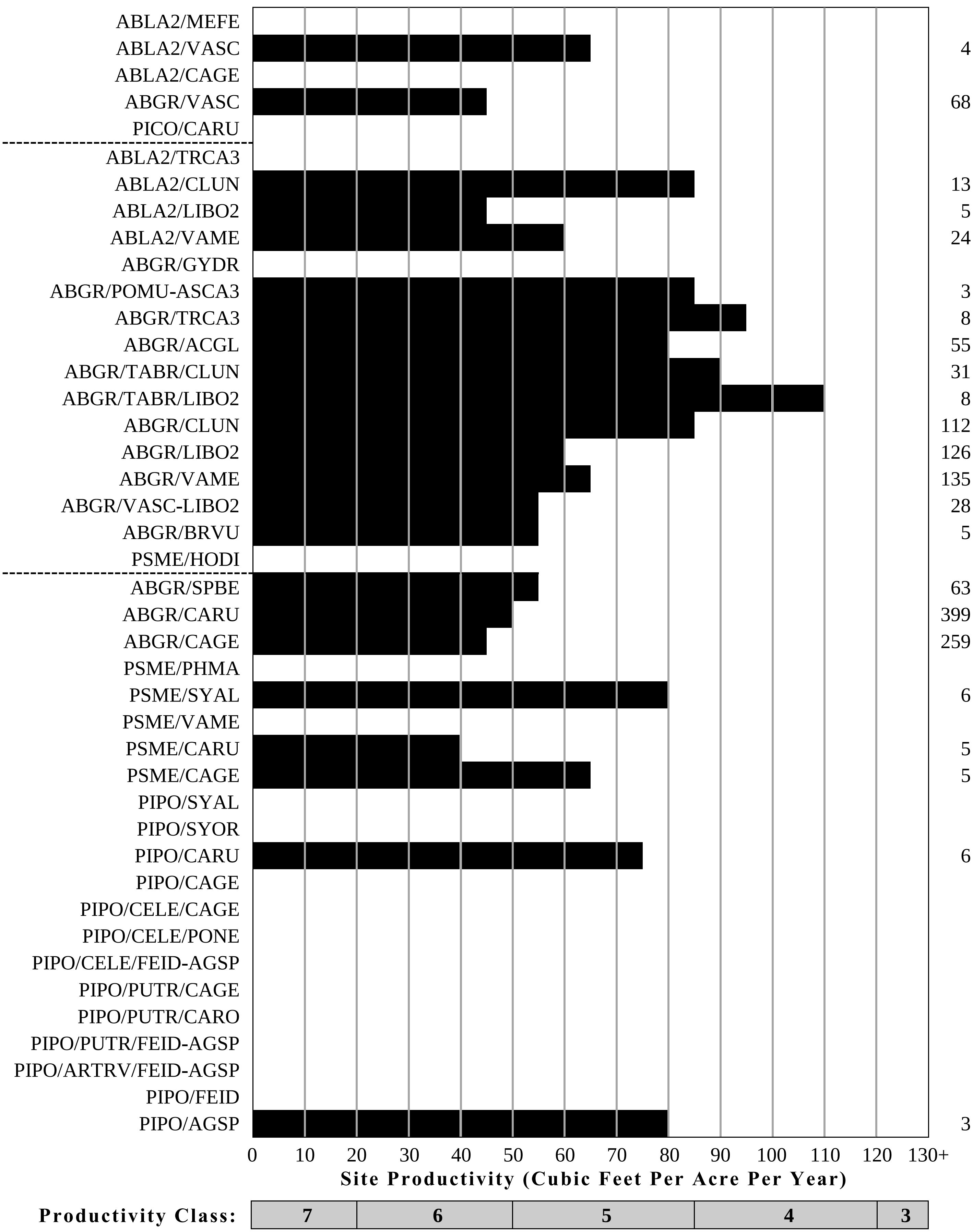
YIELD CAPABILITY FOR WESTERN LARCH



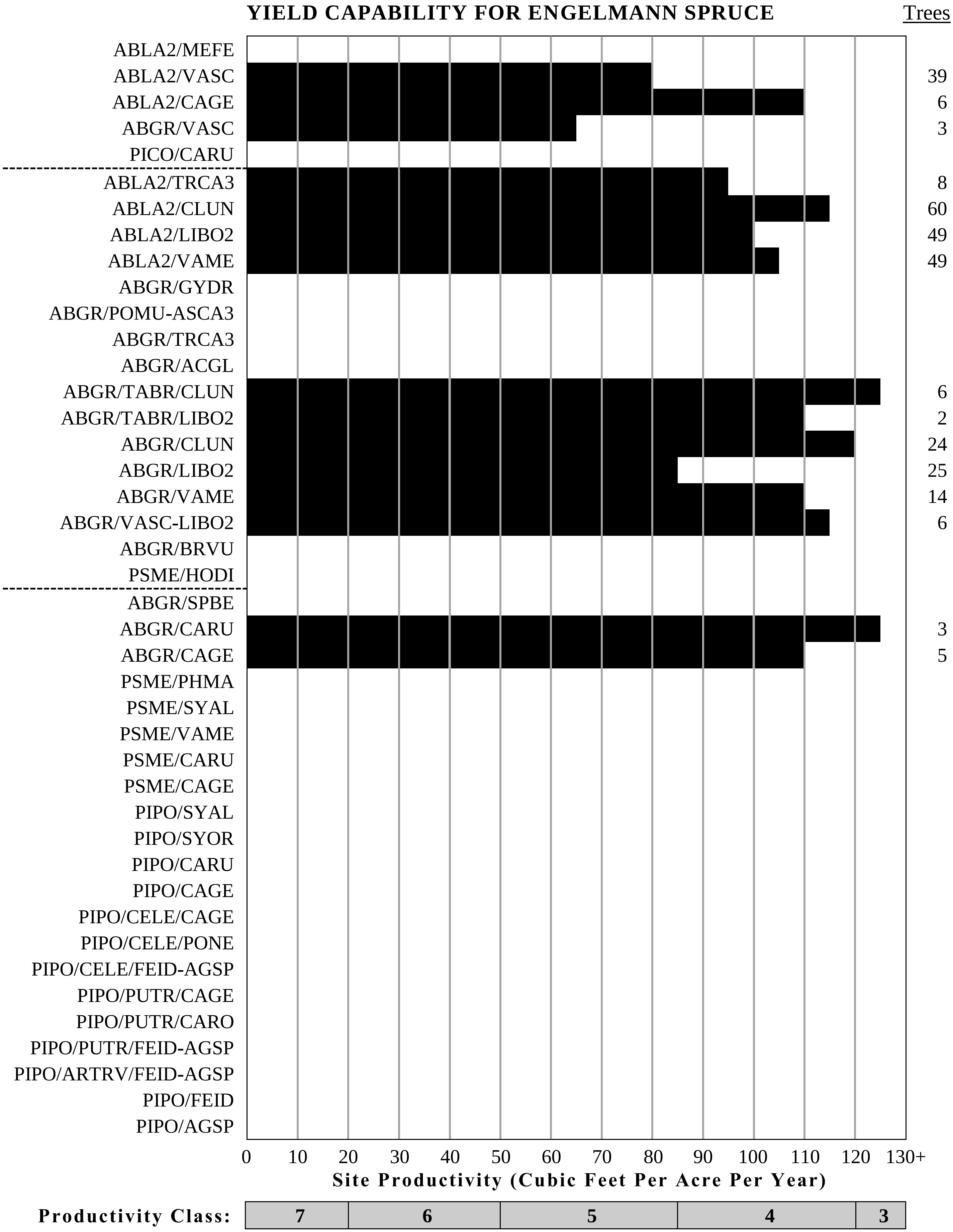
YIELD CAPABILITY FOR LODGEPOLE PINE



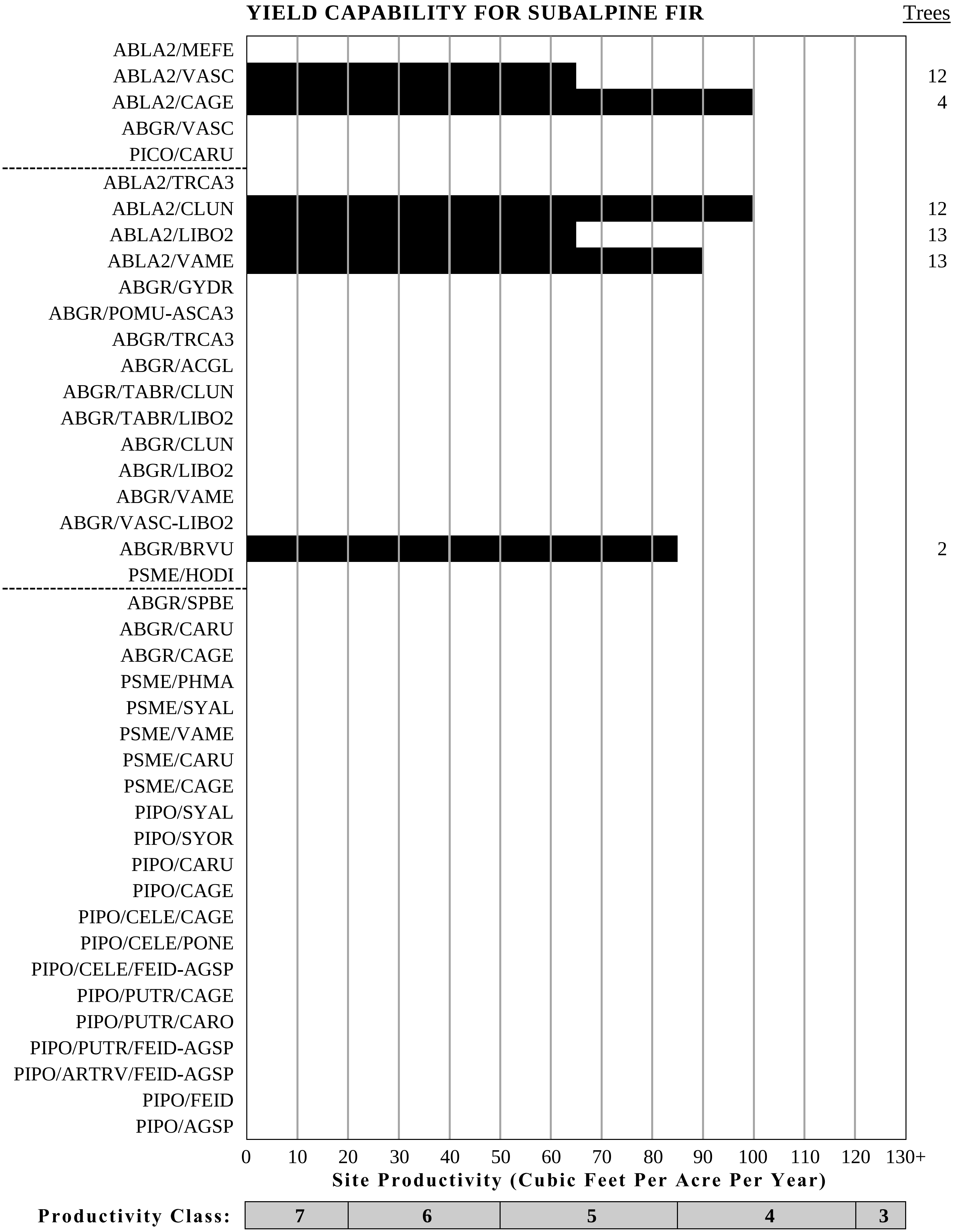
YIELD CAPABILITY FOR GRAND FIR



YIELD CAPABILITY FOR ENGELMANN SPRUCE



YIELD CAPABILITY FOR SUBALPINE FIR



Sources and Notes for the Site Productivity Charts

1. Seven charts are provided, one for each of the seven primary conifers in the Blue Mountains: ponderosa pine, interior Douglas-fir, western larch, lodgepole pine, grand fir, Engelmann spruce, and subalpine fir (organized from driest to wettest).
2. The leftmost column shows alphanumeric acronyms for plant associations of the Blue and Ochoco Mountains geographical area (such as PIPO/CARU). Acronyms are derived from scientific names for the plant associations. Plant associations and their acronyms are described in "Plant Associations of the Blue and Ochoco Mountains" (R6-ERW-TP-036-92) by Johnson and Clausnitzer (1992).
3. Within each chart, plant associations are organized by potential vegetation group (PVG), as based on Powell et al. (2007); dashed lines delineate breaks between the Dry Upland Forest (bottom of each chart), Moist Upland Forest (middle), and Cold Upland Forest PVGs (top). Within a PVG, plant associations are organized from warm and dry (bottom of the list) to cold and moist (top of the list).
4. Site productivity was derived from trees measured to estimate site index, which provides an estimate of the potential height of dominant and codominant trees as a measure of inherent site quality. The site index estimates were used to calculate a metric called yield capability (sometimes termed survey yield), which is a potential growth rate, in cubic feet per acre per year, for fully stocked stands on an area with a given site index.
5. The "Trees" column to the right of the productivity bars shows the number of site index trees that were used to calculate yield capability. If an asterisk precedes a number of trees value, it means that the site productivity estimate was derived from a plant community or plant community type for a plant association (these are seral or successional stages of a plant association).

REFERENCES

Barrett, J.W. 1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-232. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 41 p.

Base, S.R.; Fosberg, M.A. 1971. Soil-woodland correlation in northern Idaho. Northwest Science. 45(1): 1-6.

Brickell, J.E. 1970. Equations and computer subroutines for estimating site quality of eight Rocky Mountain species. Res. Pap. INT-75. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Brown, H.G.; Loewenstein, H. 1978. Predicting site productivity of mixed conifer stands in northern Idaho from soil and topographic variables. Soil Science Society of America Journal. 42(6): 967-971. doi:10.2136/sssaj1978.03615995004200060029x

Carlson, T.C.; Nimlos, T.J. 1966. Using soil series to predict site index and wood specific gravity in western Montana. Northwest Science. 40(2): 56-67.

Chen, H.Y.H.; Krestov, P.V.; Klinka, K. 2002. Trembling aspen site index in relation to environmental measures of site quality at two spatial scales. Canadian Journal of Forest Research. 32(1): 112-119. doi:10.1139/x01-179

Christensen, G.A.; Dunham, P.; Powell, D.C.; Hiserote, B. 2007. Forest resources of the Umatilla National Forest. Res. Bull. PNW-RB-253. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 38 p. http://www.treesearch.fs.fed.us/pubs/27656

Cochran, P.H. 1979a. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-251. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Cochran, P.H. 1979b. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-252. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Cochran, P.H. 1985. Site index, height growth, normal yields, and stocking levels for larch in Oregon and Washington. Res. Note PNW-424. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 24 p.

Dahms, W.G. 1975. Gross yield of central Oregon lodgepole pine. In: Baumgartner, D.M., ed. Management of lodgepole pine ecosystems: symposium proceedings. Pullman, WA: Washington State University, Cooperative Extension Service: 208-232.

Daniel, T.W.; Helms, J.A.; Baker, F.S. 1979. Principles of silviculture. 2nd ed. New York: McGraw-Hill Book Co. 500 p. isbn:0-07-015297-7

Daubenmire, R. 1973. A comparison of approaches to the mapping of forest land for intensive management. Forestry Chronicle. 49(2): 87-91. doi:10.5558/tfc49087-2

Davis, L.S.; Johnson, K.N.; Bettinger, P.S.; Howard, T.E. 2001. Forest management: to sustain ecological, economic, and social values. 4th ed. New York: McGraw-Hill. 804 p. isbn:0-07-032694-0

DeBell, D.S.; Harms, W.R.; Whitesell, C.D. 1989. Stockability: A major factor in productivity differences between *Pinus taeda* plantations in Hawaii and the southeastern United States. Forest Science. 35(3): 708-719.

Gingrich, S.F. 1964. Criteria for measuring stocking in forest stands. In: Proceedings, Society of American Foresters. Denver, CO: 198-201.

Hall, F.C. 1998. Pacific Northwest ecoclass codes for seral and potential natural communities. Gen. Tech. Rep. PNW-GTR-418. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 290 p.

Hanson, E.J.; Azuma, D.L.; Hiserote, B.A. 2002. Site index equations and mean annual increment equations for Pacific Northwest Research Station forest inventory and analysis inventories, 1985-2001. Res. Note PNW-RN-533. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 24 p.

Hegyi, F.; Jelinek, J.J.; Viszlai, J.; Carpenter, D.B.; Britneff, A.A. 1981. Site index equations and curves for the major tree species in British Columbia. Forest Inventory Report No. 1. Victoria, BC: Ministry of Forests, Inventory Branch. 54 p.

Helms, J.A., editor. 1998. The dictionary of forestry. Bethesda, MD: The Society of American Foresters. 210 p. isbn:0-939970-73-2

Johnson, C.G., Jr.; Clausnitzer, R.R. 1992. Plant associations of the Blue and Ochoco Mountains. Tech. Pub. R6-ERW-TP-036-92. Portland, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 164 p.

MacFarlane, D.W.; Green, E.J.; Burkhart, H.E. 2000. Population density influences assessment and application of site index. Canadian Journal of Forest Research. 30(9): 1472-1475. doi:10.1139/cjfr-30-9-1472

MacLean, C.D.; Bolsinger, C.L. 1973. Estimating productivity on sites with a low stocking capacity. Res. Pap. PNW-152. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Max, T.A.; Schreuder, H.T.; Hazard, J.W.; Oswald, D.D.; Teply, J.; Alegria, J. 1996. The Pacific Northwest Region vegetation and inventory monitoring system. Res. Pap. PNW-RP-493. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 22 p.

Means, J.E.; Campbell, M.H.; Johnson, G.P. 1986. Height growth and site index curves for mountain hemlock in the Oregon and southern Washington Cascades. Unpub. Rep. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 31 p.

Monserud, R.A.; Moody, U.; Breuer, D.W. 1990. A soil-site study for inland Douglas-fir. Canadian Journal of Forest Research. 20(6): 686-695. doi:10.1139/x90-092.

Parker, J. 1952. Environment and forest distribution of the Palouse Range in northern Idaho. Ecology. 33(4): 451-461. doi:10.2307/1931520

Powell, D.C. 2014. Active management of dry forests in the Blue Mountains: Silvicultural considerations. White Paper F14-SO-WP-SILV-4. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 204 p.

Powell, D.C.; Johnson, C.G., Jr.; Crowe, E.A.; Wells, A.; Swanson, D.K. 2007. Potential vegetation hierarchy for the Blue Mountains section of northeastern Oregon, southeastern Washington, and west-central Idaho. Gen. Tech. Rep. PNW-GTR-709. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 87 p. http://www.treesearch.fs.fed.us/pubs/27598

Sackville Hamilton, N.R.; Matthew, C.; Lemaire, G. 1995. In defence of the -3/2 boundary rule: a re-evaluation of self-thinning concepts and status. Annals of Botany. 76(6): 569-577. doi:10.1006/anbo.1995.1134

Smith, T.; Huston, M. 1989. A theory of the spatial and temporal dynamics of plant communities. Vegetatio. 83(1/2): 49-69.

Sprackling, J.A. 1973. Soil-topographic site index for Engelmann spruce on granitic soils in northern Colorado and southern Wyoming. Research Note RM-239. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Sterba, H. 1987. Estimating potential density from thinning experiments and inventory data. Forest Science. 33(4): 1022-1034.

USDA Forest Service. 1987. Calculations and formulas used to derive R6TSE output tables. Program User's Guide Appendix II, R6TSE Program User's Guide. Portland, OR: USDA Forest Service, Pacific Northwest Region. 16 p.

USDA Forest Service. 1995. Current vegetation survey. Version 1.5. Portland, OR: USDA Forest Service, Pacific Northwest Region, Natural Resource Inventory. 79 p.

APPENDIX: SILVICULTURE WHITE PAPERS

White papers are internal reports, and they are produced with a consistent formatting and numbering scheme – all papers dealing with Silviculture, for example, are placed in a silviculture series (Silv) and numbered sequentially. Generally, white papers receive only limited review and, in some instances pertaining to highly technical or narrowly focused topics, the papers may receive no technical peer review at all. For papers that receive no review, the viewpoints and perspectives expressed in the paper are those of the author only, and do not necessarily represent agency positions of the Umatilla National Forest or the USDA Forest Service.

Large or important papers, such as two papers discussing active management considerations for dry and moist forests (white papers Silv-4 and Silv-7, respectively), receive extensive review comparable to what would occur for a research station general technical report (but they don't receive blind peer review, a process often used for journal articles).

White papers are designed to address a variety of objectives:

(1) They guide how a methodology, model, or procedure is used by practitioners on the Umatilla National Forest (to ensure consistency from one unit, or project, to another).

(2) Papers are often prepared to address ongoing and recurring needs; some papers have existed for more than 20 years and still receive high use, indicating that the need (or issue) has long standing – an example is white paper #1 describing the Forest's big-tree program, which has operated continuously for 25 years.

(3) Papers are sometimes prepared to address emerging or controversial issues, such as management of moist forests, elk thermal cover, or aspen forest in the Blue Mountains. These papers help establish a foundation of relevant literature, concepts, and principles that continuously evolve as an issue matures, and hence they may experience many iterations through time. [But also note that some papers have not changed since their initial development, in which case they reflect historical concepts or procedures.]

(4) Papers synthesize science viewed as particularly relevant to geographical and management contexts for the Umatilla National Forest. This is considered to be the Forest's self-selected 'best available science' (BAS), realizing that non-agency commenters would generally have a different conception of what constitutes BAS – like beauty, BAS is in the eye of the beholder.

(5) The objective of some papers is to locate and summarize the science germane to a particular topic or issue, including obscure sources such as master's theses or Ph.D. dissertations. In other instances, a paper may be designed to wade through an overwhelming amount of published science (dry-forest management), and then synthesize sources viewed as being most relevant to a local context.

(6) White papers function as a citable literature source for methodologies, models, and procedures used during environmental analysis – by citing a white paper, specialist reports can include less verbiage describing analytical databases, techniques, and so forth, some of which change little (if at all) from one planning effort to another.

(7) White papers are often used to describe how a map, database, or other product was developed. In this situation, the white paper functions as a 'user's guide' for the new product. Examples include papers dealing with historical products: (a) historical fire extents for the Tucannon watershed (WP Silv-21); (b) an 1880s map developed from General Land Office survey

notes (WP Silv-41); and (c) a description of historical mapping sources (24 separate items) available from the Forest's history website (WP Silv-23).

The following papers are available from the Forest's website: Silviculture White Papers

Paper #	Title
1	Big tree program
2	Description of composite vegetation database
3	Range of variation recommendations for dry, moist, and cold forests
4	Active management of dry forests in the Blue Mountains: silvicultural considerations
5	Site productivity estimates for upland forest plant associations of the Blue and Ochoco Mountains
6	Fire regimes of the Blue Mountains
7	Active management of moist forests in the Blue Mountains: silvicultural considerations
8	Keys for identifying forest series and plant associations of the Blue and Ochoco Mountains
9	Is elk thermal cover ecologically sustainable?
10	A stage is a stage is a stage…or is it? Successional stages, structural stages, seral stages
11	Blue Mountains vegetation chronology
12	Calculated values of basal area and board-foot timber volume for existing (known) values of canopy cover
13	Created opening, minimum stocking level, and reforestation standards from the Umatilla National Forest land and resource management plan
14	Description of EVG-PI database
15	Determining green-tree replacements for snags: a process paper
16	Douglas-fir tussock moth: a briefing paper
17	Fact sheet: Forest Service trust funds
18	Fire regime condition class queries
19	Forest health notes for an Interior Columbia Basin Ecosystem Management Project field trip on July 30, 1998 (handout)
20	Height-diameter equations for tree species of the Blue and Wallowa Mountains
21	Historical fires in the headwaters portion of the Tucannon River watershed
22	Range of variation recommendations for insect and disease susceptibility
23	Historical vegetation mapping
24	How to measure a big tree
25	Important insects and diseases of the Blue Mountains
26	Is this stand overstocked? An environmental education activity
27	Mechanized timber harvest: some ecosystem management considerations
28	Common plants of the south-central Blue Mountains (Malheur National Forest)
29	Potential natural vegetation of the Umatilla National Forest
30	Potential vegetation mapping chronology
31	Probability of tree mortality as related to fire-caused crown scorch

Paper #	Title
32	Review of the "Integrated scientific assessment for ecosystem management in the interior Columbia basin, and portions of the Klamath and Great basins" – forest vegetation
33	Silviculture facts
34	Silvicultural activities: description and terminology
35	Site potential tree height estimates for the Pomeroy and Walla Walla ranger districts
36	Tree density protocol for mid-scale assessments
37	Tree density thresholds as related to crown-fire susceptibility
38	Umatilla National Forest Land and Resource Management Plan: forestry direction
39	Updates of maximum stand density index and site index for the Blue Mountains variant of the Forest Vegetation Simulator
40	Competing vegetation analysis for the southern portion of the Tower Fire area
41	Using General Land Office survey notes to characterize historical vegetation conditions for the Umatilla National Forest
42	Life history traits for common conifer trees of the Blue Mountains
43	Timber volume reductions associated with green-tree snag replacements
44	Density management field exercise
45	Climate change and carbon sequestration: vegetation management considerations
46	The Knutson-Vandenberg (K-V) program
47	Active management of quaking aspen plant communities in the northern Blue Mountains: regeneration ecology and silvicultural considerations
48	The Tower Fire…then and now. Using camera points to monitor postfire recovery
49	How to prepare a silvicultural prescription for uneven-aged management
50	Stand density conditions for the Umatilla National Forest: a range of variation analysis
51	Restoration opportunities for upland forest environments of the Umatilla National Forest
52	New perspectives in riparian management: Why might we want to consider active management for certain portions of riparian habitat conservation areas?
53	Eastside Screens chronology
54	Using mathematics in forestry: an environmental education activity
55	Silviculture certification: tips, tools, and trip-ups
56	Vegetation polygon mapping and classification standards: Malheur, Umatilla, and Wallowa-Whitman national forests
57	The state of vegetation databases on the Malheur, Umatilla, and Wallowa-Whitman national forests

REVISION HISTORY

November 2010: minor formatting and editing changes were made; an appendix was added describing the white paper system, including a list of available white papers.

December 2014: minor formatting and editing changes were made; a new section called "Is site index the best predictor of site productivity?" was added, including figure 1 and additional references.